Module 14

Channel and Flood Protection

Virginia Department of Environmental Quality

14a. Channel Protection Criteria

& the Energy Balance Method

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Water Quantity Criteria Channel Protection

9VAC25-870-66. B

Channel Protection

Natural	Man-made	Restored
EB	EB or 2-yr	EB or Design

-----------TO LIMITS OF ANALYSIS-----------

9VAC25-870-66. Water quantity.

Channel Protection:

Concentrated stormwater flow shall be released in to a stormwater conveyance system:

Photo: Williamsburg Environmental Group

Photo: City of Charlottesville

System Capacity

*"**Manmade stormwater conveyance system**" means a pipe, ditch, vegetated swale, or other stormwater conveyance system constructed by man except for restored stormwater conveyance systems*

System Capacity

*"**Restored stormwater conveyance system**" means a stormwater conveyance system that has been designed and constructed using natural channel design concepts. Includes the main channel and the flood-prone area adjacent to the main channel.*

Photo: Williamsburg Environmental Group

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Manmade stormwater conveyance system:

- Non-erosive capacity for **2-yr peak** flow to **Limits of Analysis**
  OR
- Energy Balance (Natural Stormwater Conveyance)

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Restored stormwater conveyance system:

- Development (density, scale, etc.) and peak flow rate consistent with the design parameters of the restored system to **the Limits of Analysis** analysis **OR**
- Energy Balance (Natural Stormwater Conveyance)

Photo: City of Charlottesville

Water Quantity Control Compliance

Limits of Analysis:

- Channel protection analysis carried to a point where:
  - Site's ***contributing DA*** is < 1% of total watershed area **or**
  - Site's ***1-yr contributing peak flow rate*** is < 1% of total watershed area (before implementation of any quantity BMPs)

System Capacity

*"**Natural stormwater conveyance system**" means the main channel of a natural stream and the flood-prone area adjacent to the main channel.*

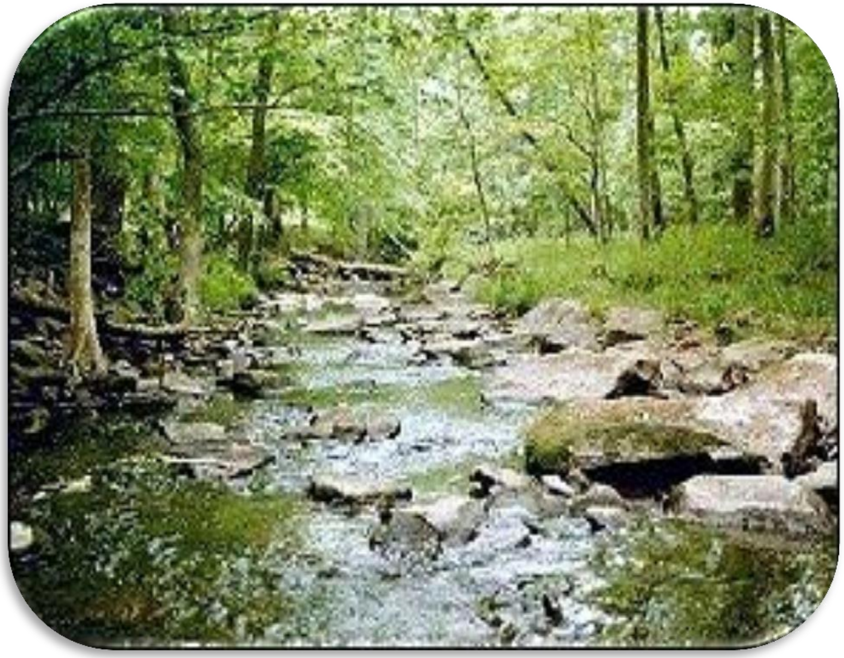

Photo: Ellanor C. Lawrence Park Fairfax, County

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Criteria for the Protection of Natural Channels

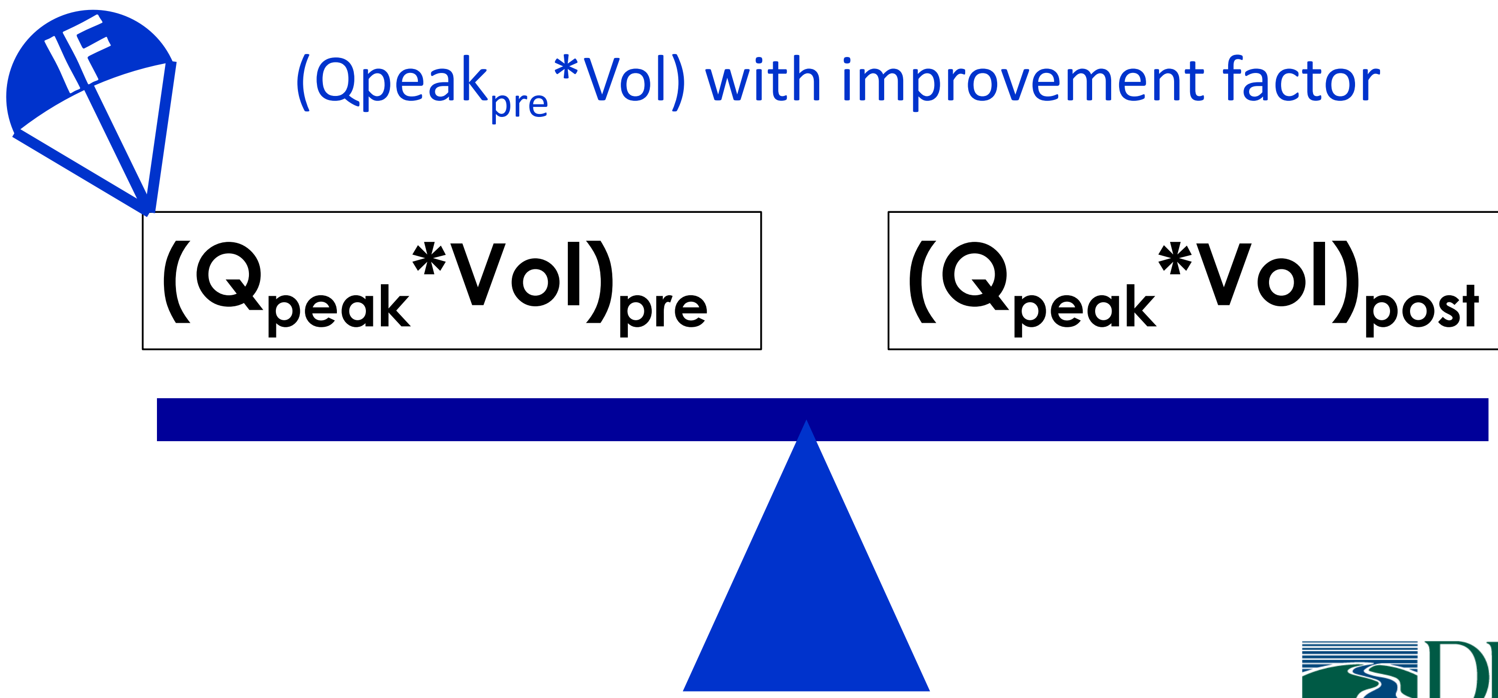
Protection of natural stream channels

- Restore them using natural channel design
- Protect them using the Energy Balance Method (1-yr event)
- Safe Harbor Provision (from SWM Law § 62.1-44.15:28.10)

Energy Balance

Goal: Establish "balance" exerted by pre- and post-developed stormwater discharge

$(Qpeak_{pre}{*}Vol)$ with improvement factor



What is Energy Balance & Why use it?

Post-development runoff volume increases

Allowable discharge decreases

Simple **"balance"** offsets increase in volume and peak flow of developed condition hydrology

DO NOT BRING TO EXAM

Stormwater Quantity Channel Protection

9VAC25-870-66.A

Energy Balance

Post ($Vol_{1\text{-}yr}$ * Peak $Q_{1\text{-}yr}$) **≤ Pre** ($Vol_{1\text{-}yr}$ * Peak $Q_{1\text{-}yr}$)(IF)

$$Q_{1post} \leq Q_{1pre}\left(\frac{PreVol_{1}}{Post\ Vol_{1}}\right)(IF)$$

IF = Improvement Factor:

0.8 for sites > 1 acre or ***0.9 for sites ≤ 1 acre***

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Stormwater Quantity Channel Protection

9VAC25-870-66.A

Energy Balance

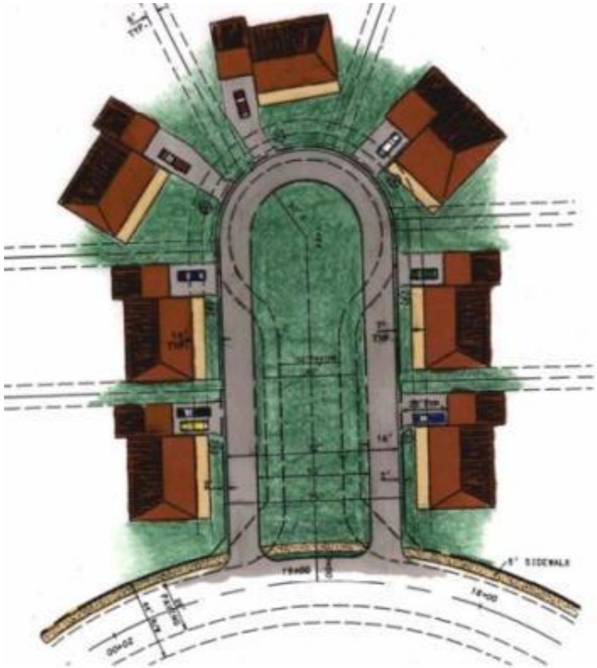
Under no condition shall:

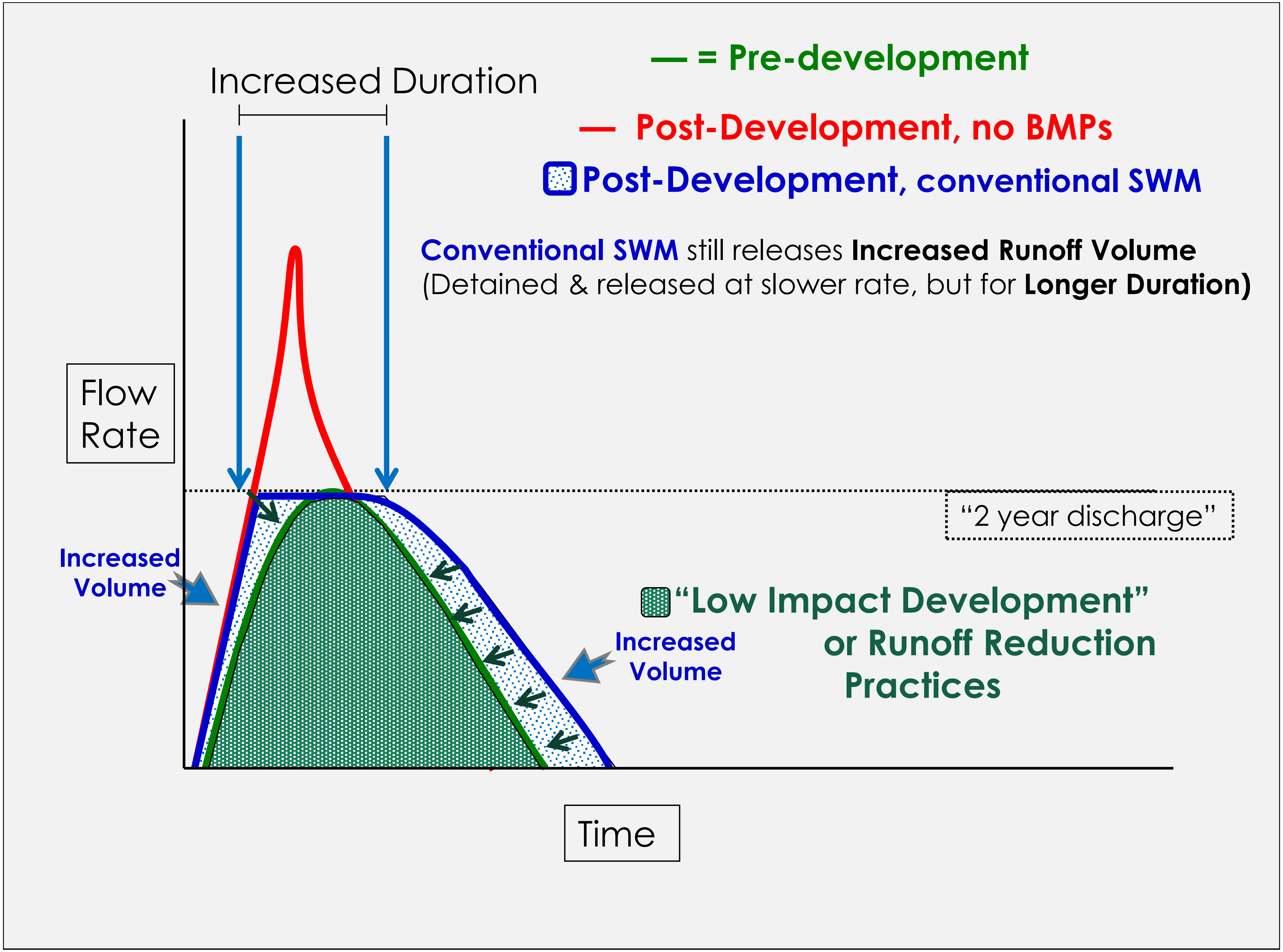
$$Q_{1\ post} > Q_{1\ pre}$$

$$Q_{1\ post} < Q_{1\ forest} * \text{Forest } Vol_1/Post\ Vol_1$$

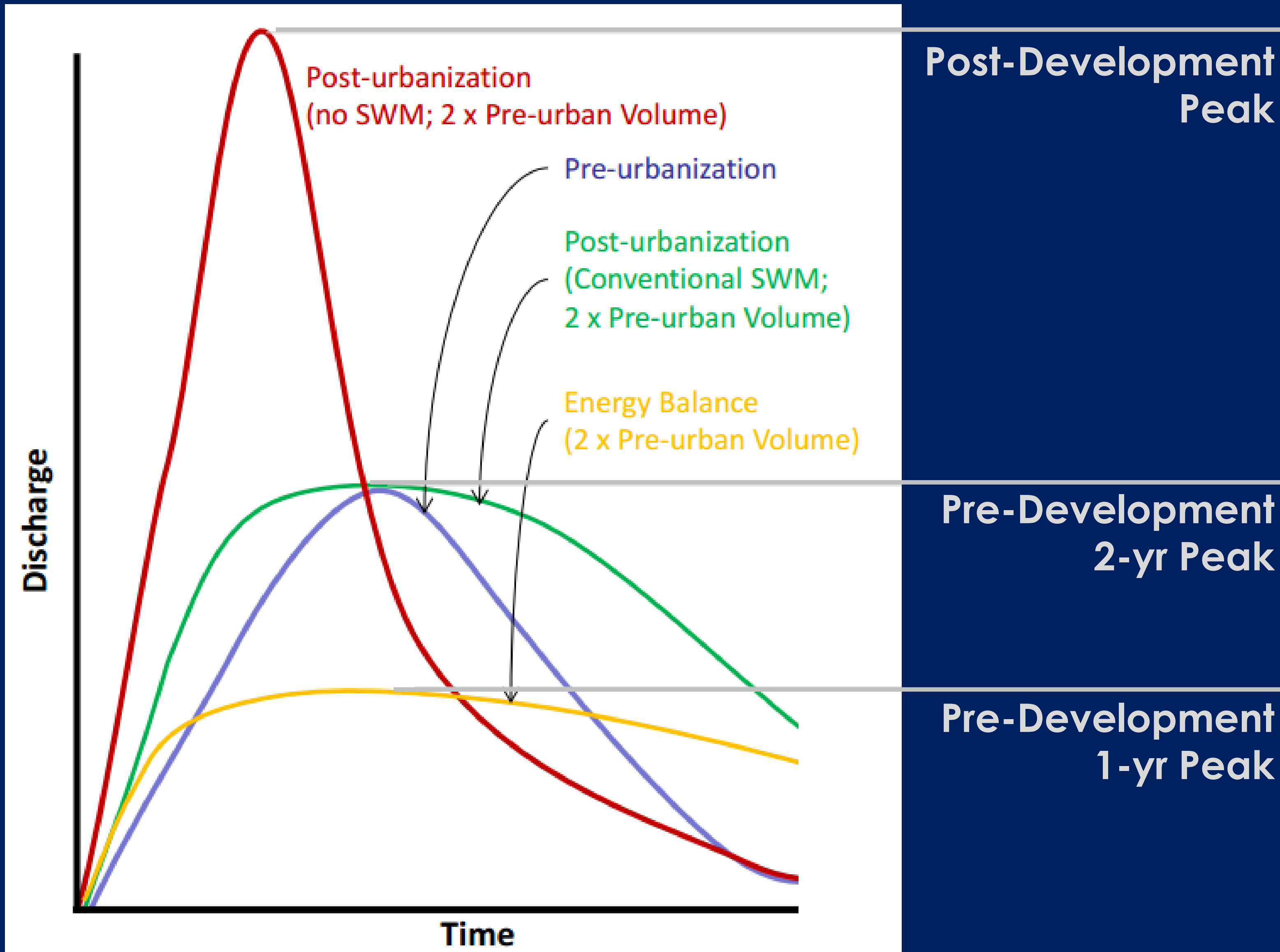
Why Energy Balance?

§ 62.1-44.15:28 A.11.




Increased Duration
— = Pre-development
— Post-Development, no BMPs
Post-Development, conventional SWM
Conventional SWM still releases Increased Runoff Volume
(Detained & released at slower rate, but for Longer Duration)
Flow Rate
"2 year discharge"
Increased Volume
"Low Impact Development" or Runoff Reduction Practices
Increased Volume
Time

Energy Balance



How Does Energy Balance encourage ESD?

- RUNOFF REDUCTION
  - Decrease volume by
    - **self-crediting site design**
      - Less impervious cover
      - Minimizing impacts to native vegetation
      - Minimize impacts to native soils
    - utilizing **structural** and **non-structural Runoff Reduction practices**

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How Does Energy Balance encourage ESD?

- VRRM Spreadsheet calculates volume reduction with **double credit**:
  - **Reduced** Vol_{post1} → Energy Balance
  - **Reduced** Curve Number (CN) → Q_{1post}

How Does Energy Balance encourage ESD?

$$Q_{1post} \leq Q_{1pre}\left(\frac{Pre\,Vol_1}{Post\,Vol_1}\right)(IF)$$

- As *Post Vol₁* reduced
- *Pre Vol₁* to *Post Vol₁* ratio increases
- Allowable Q_{1post} increases

***Decreases storage required for peak flow**

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Improvement Factor (*IF*)

§ 62.1-44.15:28

- Requires stormwater regulations to *improve upon contributing share of existing predevelopment runoff characteristics and site hydrology . . . .*
- At minimum, pre-developed discharge will be reduced using factor of 0.8 or 0.9

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Energy Balance Terminology

$$Q_{1post} \leq Q_{1pre}\left(\frac{PreVol_1}{Post\ Vol_1}\right)(IF)$$

Description	Units	Term
NRCS TR-55		
Runoff Depth	inches (in)	*Q*
Runoff Volume	cubic feet (ft^3) or acre feet (ac.ft.)	*Vr*
Storage Volume	cubic feet (ft^3) or acre feet (ac.ft.)	*Vs*
Peak Discharge	cubic feet per second (cfs)	q_p
VRRM Treatment Volume Runoff Coefficients		
Unit-less Volumetric Runoff Coefficients		*Rv*
VRRM Curve Number Adjustment		
Runoff Depth	inches	*RV*
VSMP Regulations Channel Protection Criteria (4VAC50-60-66.B)		
Peak Discharge	cubic feet per second (cfs)	*Q*
Runoff Volume*	cubic feet (ft^3) or acre feet (ac.ft.)*	*RV*

*Units of volume in the VSMP regulations Channel Protection Criteria can also be expressed in terms of *watershed-inches* or inches (consistent with Runoff Depth as expressed in the VRRM *CN* adjustment.

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Energy Balance: 9VAC25-870-66.A

How would you write this equation?

$$Q_{1post} \le Q_{1pre} \left(\frac{RV_{pre1}}{RV_{post1}} \right) (IF)$$

(Regulation)

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Energy Balance: 9VAC25-870-66.A

How would you write this equation?

$$Q_{1post} \leq Q_{1pre} \left(\frac{RV_{pre1}}{RV_{post1}} \right) (IF)$$ ***(Regulation)***

$$Q_{1post} \leq Q_{1pre} \left(\frac{PreVol_{1}}{Post\,Vol_{1}} \right) (IF)$$ ***(Simplified)***

Energy Balance: 9VAC25-870-66.A

How would you write this equation?

$$Q_{1post} \le Q_{1pre}\left(\frac{RV_{pre1}}{RV_{post1}}\right)(IF) \qquad \textbf{\textit{(Regulation)}}$$

$$Q_{1post} \le Q_{1pre}\left(\frac{PreVol_1}{Post\ Vol_1}\right)(IF) \qquad \textbf{\textit{(Simplified)}}$$

$$q_{1post} \le q_{1pre}\left(\frac{Vr_{pre1}}{Vr_{post1}}\right)(IF) \qquad \textbf{\textit{(TR-55)}}$$

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14b. Energy Balance Design Example

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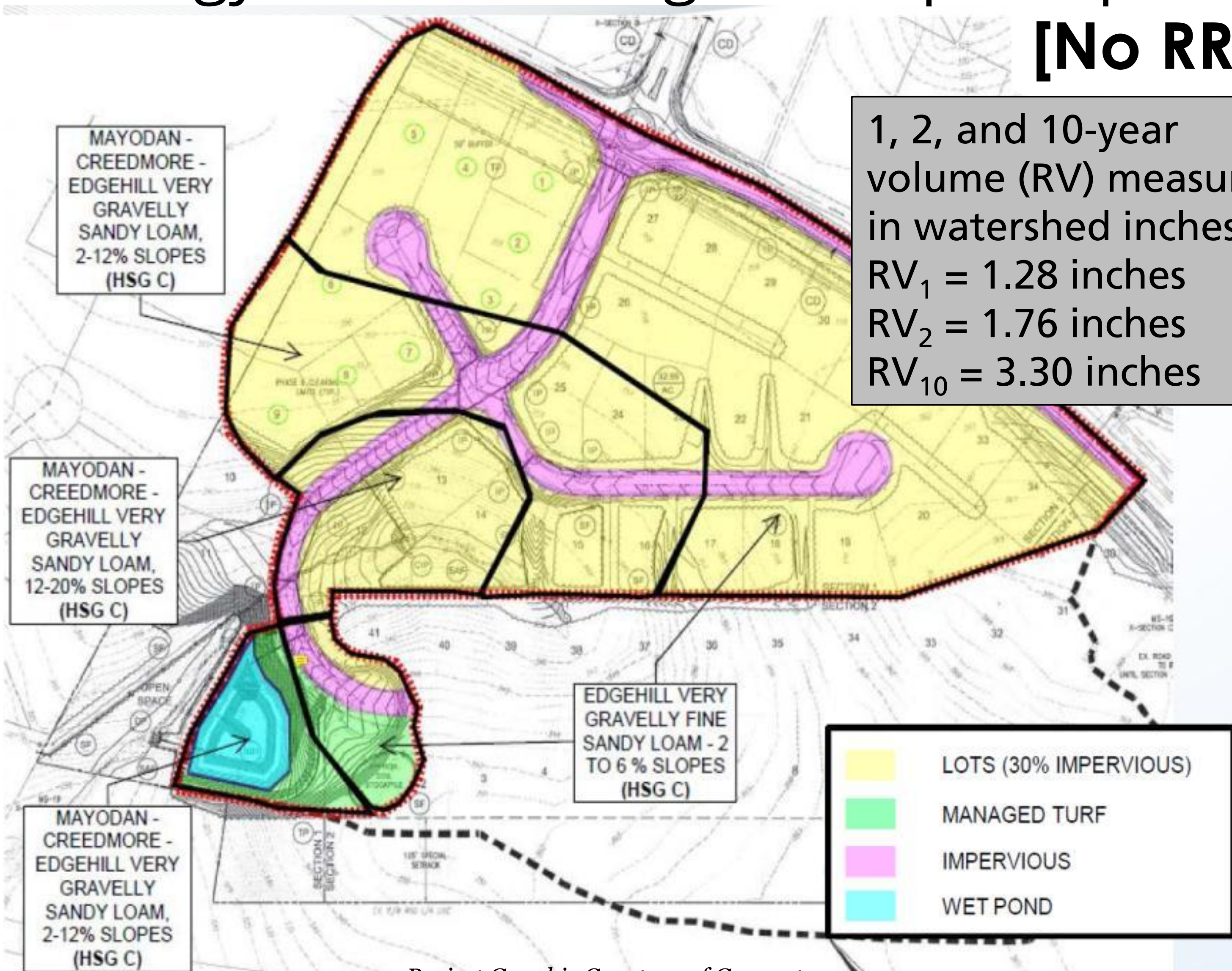
Energy Balance Design Example: Option 1 **[No RR]**

1, 2, and 10-year volume (RV) measured in watershed inches
RV_1 = 1.28 inches
RV_2 = 1.76 inches
RV_{10} = 3.30 inches



Project Graphic Courtesy of Geosyntec

Where Does the Runoff Depth come From?

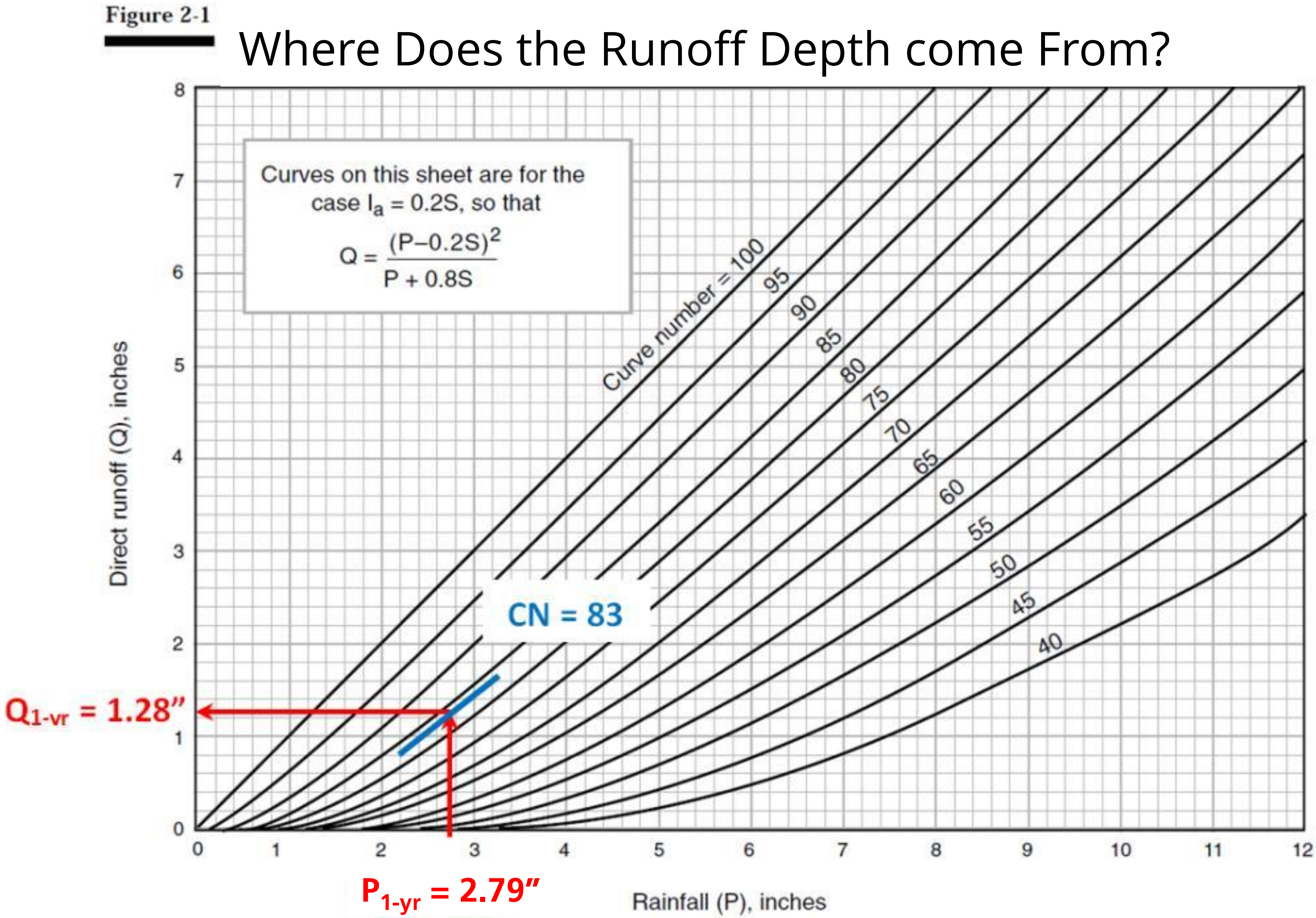


Table 2-1 Runoff depth for selected CN's and rainfall amounts [1]

Where Does the Runoff Depth come From?

CN = 83

$P_{1\text{-yr}}$ = 2.79”

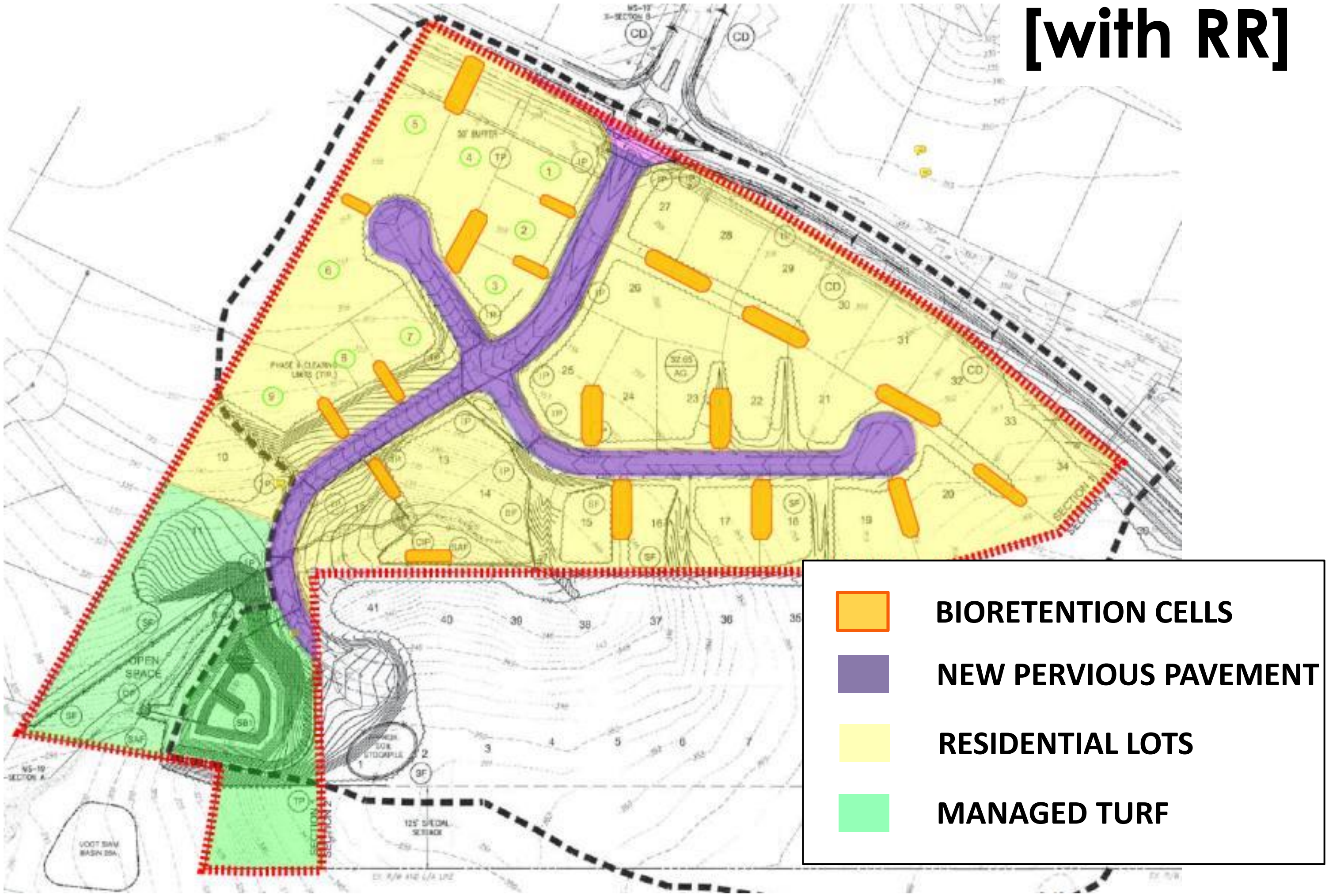
1.28”

Rainfall	Runoff depth for curve number of— 40	45	50	55	60	65	70	75	80	85	90	95	98
	inches												
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	.00	.00	.00	.00	.00	.00	.03	.07	.15	.27	.46	.74	.99
1.4	.00	.00	.00	.00	.00	.02	.06	.13	.24	.39	.61	.92	1.18
1.6	.00	.00	.00	.00	.01	.05	.11	.20	.34	.52	.76	1.11	1.38
1.8	.00	.00	.00	.00	.03	.09	.17	.29	.44	.65	.93	1.29	1.58
2.0	.00	.00	.00	.02	.06	.14	.24	.38	.56	.80	1.09	1.48	1.77
2.5	.00	.00	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
3.0	.00	.02	.09	.19	.33	.51	.71	.96	1.25	1.59	1.98	2.45	2.77
3.5	.02	.08	.20	.35	.53	.75	1.01	1.30	1.64	[illegible]	2.45	2.94	3.27
4.0	.06	.18	.33	.53	.76	1.03	1.33	1.67	2.04	[illegible]	2.92	3.43	3.77
4.5	.14	.30	.50	.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	.24	.44	.69	.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	.50	.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1] Interpolate the values shown to obtain runoff depths for CN's or rainfall amounts not shown.

Energy Balance Design Example: Option 2

[with RR]



Project Graphic Courtesy of Geosyntec

DO NOT BRING TO EXAM

Channel & Flood Protection Tab

	A	B	C	D	E	F	G	H
1				1-year storm	2-year storm	10-year storm		
2	Target Rainfall Event (in)			2.79	3.38	5.14		
3								
4	Drainage Area A							
5	Drainage Area (acres)		19.80					
6	Runoff Reduction Volume (cf)		23,065					
7								
8	Drainage Area B							
9	Drainage Area (acres)		0.00					
10	Runoff Reduction Volume (cf)		0					
11								
12	Drainage Area C							
13	Drainage Area (acres)		0.00					
14	Runoff Reduction Volume (cf)		0					
15								
16	Drainage Area D							
17	Drainage Area (acres)		0.00					
18	Runoff Reduction Volume (cf)		0					
19								
20	Drainage Area E							
21	Drainage Area (acres)		0.00					
22	Runoff Reduction Volume (cf)		0					
23								
24								
25	Based on the use of Runoff Reduction practices in the selected drainage areas, the spreadsheet calculates an adjusted $RV_{Developed}$ and adjusted Curve Number.							
26								
27	Drainage Area A			A soils	B Soils	C Soils	D Soils	
28	Forest/Open Space -- undisturbed, protected forest/open		Area (acres)	0.00	0.00	0.40	0.00	
29	space or reforested land		CN	30	55	70	77	
30	Managed Turf -- disturbed, graded for yards or other turf to be		Area (acres)	0.00	0.00	12.13	0.00	
31	mowed/managed		CN	39	61	74	80	
32			Area (acres)	0.00	0.00	7.27	0.00	
33	Impervious Cover		CN	98	98	98	98	
34							Weighted CN	S
35							83	2.05
36				1-year storm	2-year storm	10-year storm		
37			$RV_{Developed}$ (in) with no Runoff Reduction	1.28	1.76	3.30		
38			$RV_{Developed}$ (in) with Runoff Reduction	0.96	1.44	2.98		
39			Adjusted CN	77	78	80		

1, 2, and 10-year storm rainfall depths

Volume Reduction = 23,065 ft^3

1, 2, and 10-year volume (RV) reduction =

RV_1 = 1.28” ➡ 0.96”

CN_1 = 83 ➡ 77

RV_2 = 1.76” ➡ 1.44”

CN_2 = 83 ➡ 78

RV_{10} = 3.30” ➡ 2.98”

CN_{10} = 83 ➡ 80

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Curve Number Adjustment: Hydrograph Modification

Runoff Depth Equations (TR-55):

Eq. 2-1: $$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Eq. 2-2: $$I_a = 0.2\,S$$

Eq. 2-4: $$S = \left(\frac{1000}{CN}\right) - 10$$

Where:

- Q = runoff depth (in)
- P = precipitation depth (in)
- S = potential maximum retention after runoff begins
- I_a = initial abstraction, volume that must be filled before runoff begins

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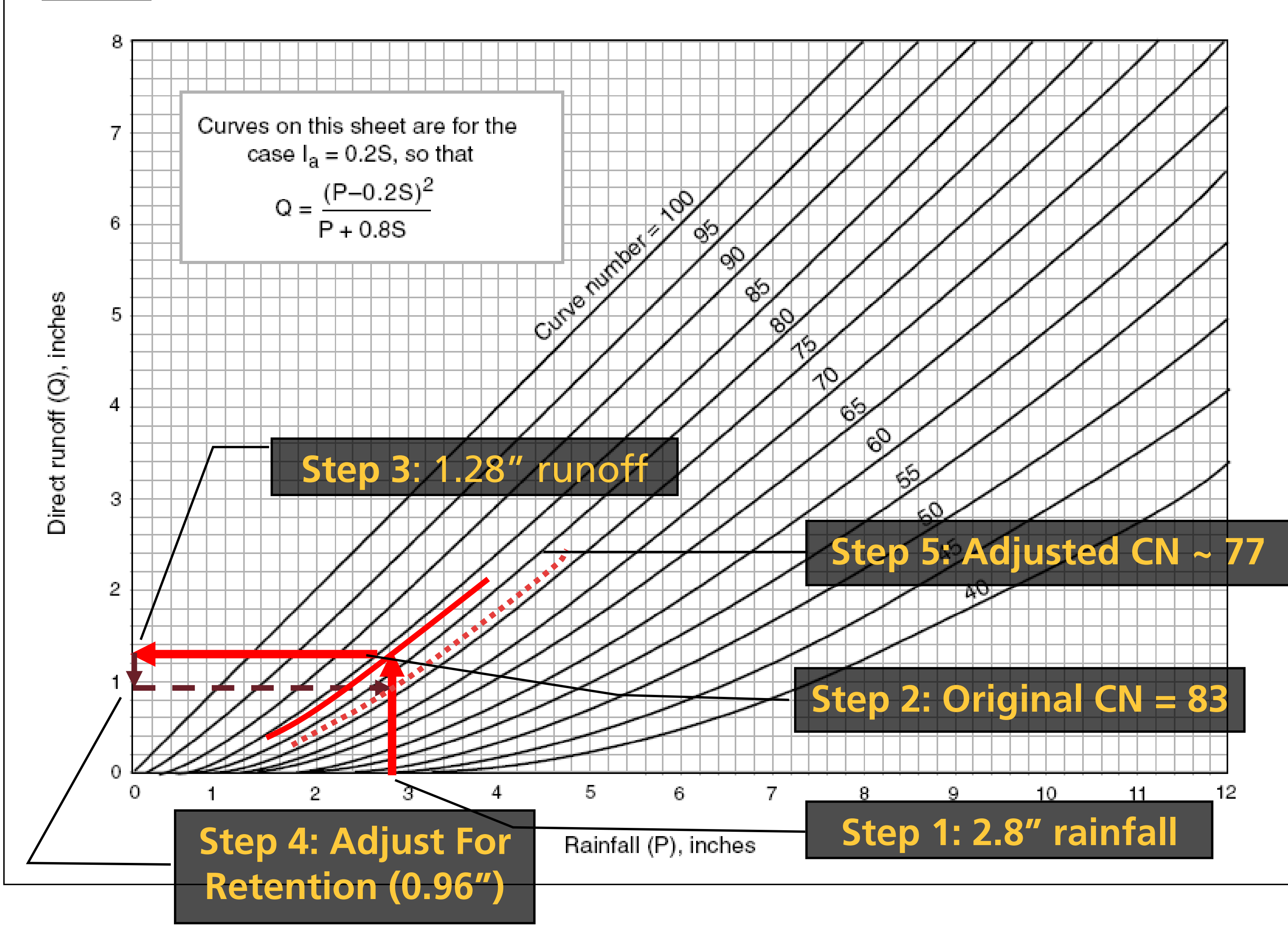
Figure 2-1 Solution of runoff equation.



Channel & Flood Protection Tab

	1-year storm	2-year storm	10-year storm
Target Rainfall Event (in)	2.79	3.38	5.14

Drainage Area A	
Drainage Area (acres)	19.80
Runoff Reduction Volume (cf)	23,065
Drainage Area B	
Drainage Area (acres)	0.00
Runoff Reduction Volume (cf)	0
Drainage Area C	
Drainage Area (acres)	0.00
Runoff Reduction Volume (cf)	0
Drainage Area D	
Drainage Area (acres)	0.00
Runoff Reduction Volume (cf)	0
Drainage Area E	
Drainage Area (acres)	0.00
Runoff Reduction Volume (cf)	0

Based on the use of Runoff Reduction practices in the selected drainage areas, the spreadsheet calculates an adjusted $RV_{Developed}$ and adjusted Curve Number.

Drainage Area A		A soils	B Soils	C Soils	D Soils
Forest/Open Space -- undisturbed, protected forest/open space or reforested land	Area (acres)	0.00	0.00	0.40	0.00
	CN	30	55	70	77
Managed Turf -- disturbed, graded for yards or other turf to be mowed/managed	Area (acres)	0.00	0.00	12.13	0.00
	CN	39	61	74	80
Impervious Cover	Area (acres)	0.00	0.00	7.27	0.00
	CN	98	98	98	98

Weighted CN	S
83	2.05

	1-year storm	2-year storm	10-year storm
$RV_{Developed}$ (in) with no Runoff Reduction	1.28	1.76	3.30
$RV_{Developed}$ (in) with Runoff Reduction	0.96	1.44	2.98
Adjusted CN	77	78	80

1, 2, and 10-year storm rainfall depths

Volume Reduction = 23,065 ft^3

1, 2, and 10-year volume (RV) reduction =

RV_1 = 1.12” → 0.96”

CN_1 = 83 → 77

RV_2 = 1.54” → 1.44”

CN_2 = 83 → 78

RV_{10} = 2.98” → 2.98”

CN_{10} = 83 → 80

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Energy Balance Design Example

One-Year Storm Hydrology Summary: 19.8 acres			
	Pre-Developed	**Post-Developed no RR**	**Post-Developed with RR**
Runoff Curve Number	71	83	77
Runoff Volume (RV)	0.62 in	1.28 in	0.96 in
Runoff Volume	1.02 ac-ft.	2.11 ac-ft.	1.58 ac-ft.
k Discharge (q_1)	9 cfs	39 cfs	27 cfs
Post Developed EB Allowed Peak Discharge (cfs)			
Storage Volume Reqd., (ac-ft)			

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Energy Balance Design Example

- Compute the Energy Balance (EB) Allowed Peak Discharge (with and without RR):

$$q_{1post} \leq q_{1pre}\left(\frac{Vr_{pre1}}{Vr_{post1}}\right)(IF)$$

without RR

$$q_{1post} \leq 9\ cfs\left(\frac{0.62''}{1.28''}\right)(0.8)$$

$$q_{1post} \leq 3.5\ cfs$$

with RR

$$q_{1post} \leq 9\ cfs\left(\frac{0.62''}{0.96''}\right)(0.8)$$

$$q_{1post} \leq 4.7\ cfs$$

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Energy Balance Design Example

One-Year Storm Hydrology Summary: 19.8 acres			
	Pre-Developed	**Post-Developed no RR**	**Post-Developed with RR**
Runoff Curve Number	71	83	77
Runoff Volume (RV)	0.62 in	1.28 in	0.96 in
Runoff Volume	1.02 ac-ft.	2.11 ac-ft.	1.58 ac-ft.
Peak Discharge (q_1)	9 cfs	39 cfs	27 cfs
Post Developed EB Allowed Peak Discharge (cfs)		**3.5 cfs***	**4.7 cfs***

1. **Increase in allowable discharge!**
2. **Energy Balance discharge not required to be less than ratio reduction for Forested condition**

Energy Balance Design Example

One-Year Storm Hydrology Summary: 19.8 acres			
	Pre-Developed	**Post-Developed no RR**	**Post-Developed with RR**
Runoff Curve Number	71	83	77
Runoff Volume (RV)	0.62 in	1.28 in	0.96 in
Runoff Volume	1.02 ac-ft.	2.11 ac-ft.	1.58 ac-ft.
k Discharge (q_1)	9 cfs	39 cfs	27 cfs
Post Developed EB Allowed Peak Discharge (cfs)		**3.5 cfs**	**4.7 cfs**
Storage Volume Reqd. (ac-ft)		**1.16 ac-ft.***	**0.76 ac-ft.***

37% Reduction in required 1-yr Channel Protection Storage Volume

14c. Flood Protection

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

Water Quantity Criteria Flood Protection

9VAC25-870-66. C

No Flooding:

Demonstrate:

- No 10-yr flooding pre
- No 10-yr flooding post (detention/improvements)

---TO LIMITS OF ANALYSIS---

Local Flooding:

Must eliminate flooding by:

- on-site detention
- system improvements
- Combination

---TO LIMITS OF ANALYSIS---

OR

- Detention of 10-year peak flow to less than existing

--NO LIMITS OF ANALYSIS (POST)--

Water Quantity Control Compliance

Limits of Analysis:

- Downstream capacity analysis carried to a point where:
  - Site's ***contributing DA*** is < 1% of total watershed area **or**
  - Site's ***10-yr contributing peak flow rate*** is < 1% of total watershed area (before implementation of any quantity detention)
  - Storm water conveyance system enters mapped floodplain/flood-prone area

14d. Sheet Flow

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Sheet Flow

9VAC25-870-66. Water quantity.

D. Increased volumes of sheet flow resulting from pervious or disconnected impervious areas, or from physical spreading of concentrated flow through level spreaders, must be identified and evaluated for potential impacts on down-gradient properties or resources.

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Sheet Flow
9VAC25-870-66. D

- ↑volumes of sheet flow must be identified and evaluated
- ↑volumes of sheet flow creating impacts must be diverted to stormwater management facility or conveyance system

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Questions?